ESC201T : Introduction to Electronics

Lecture 23: Power Supply (part-1)

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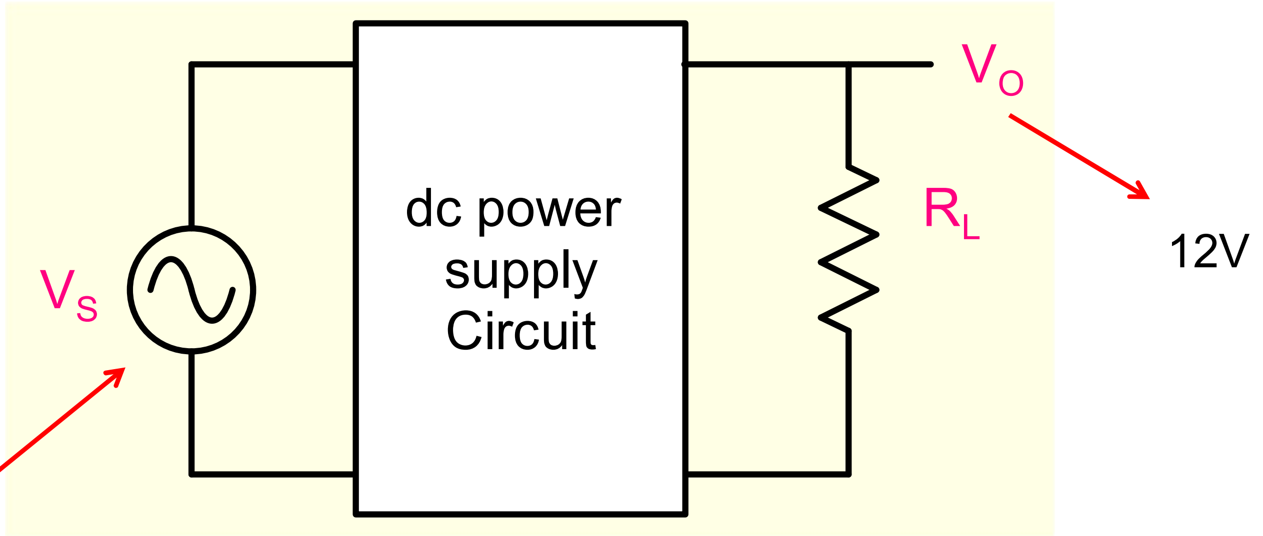
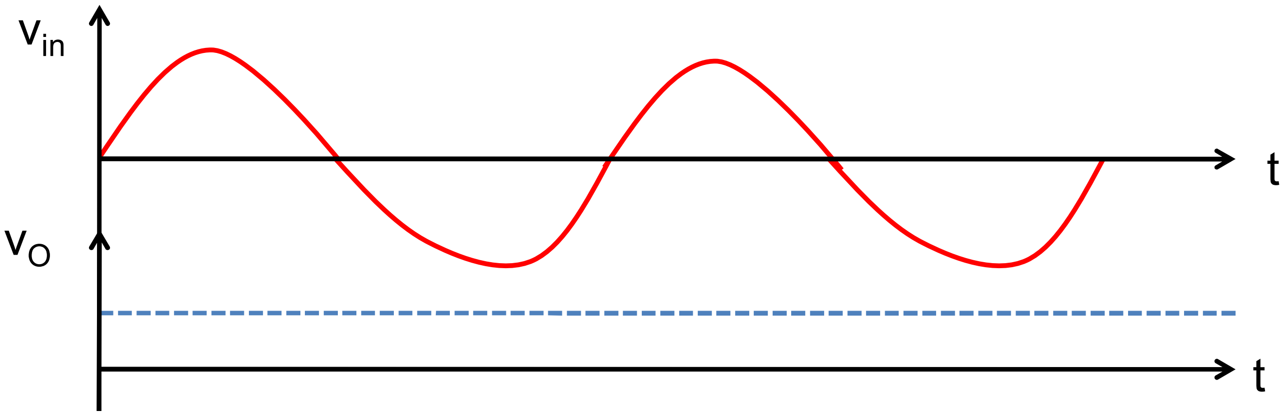
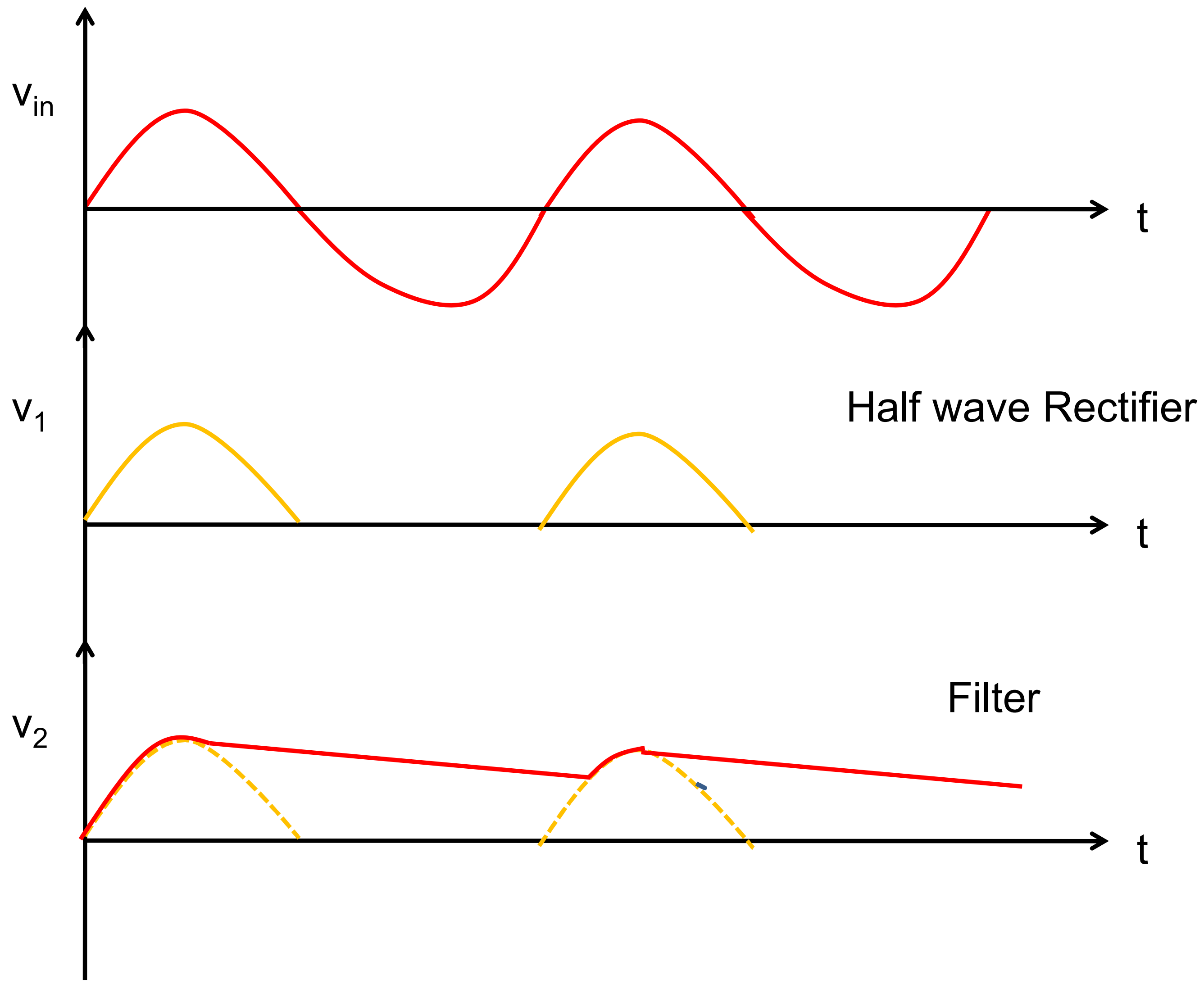
Power Supply



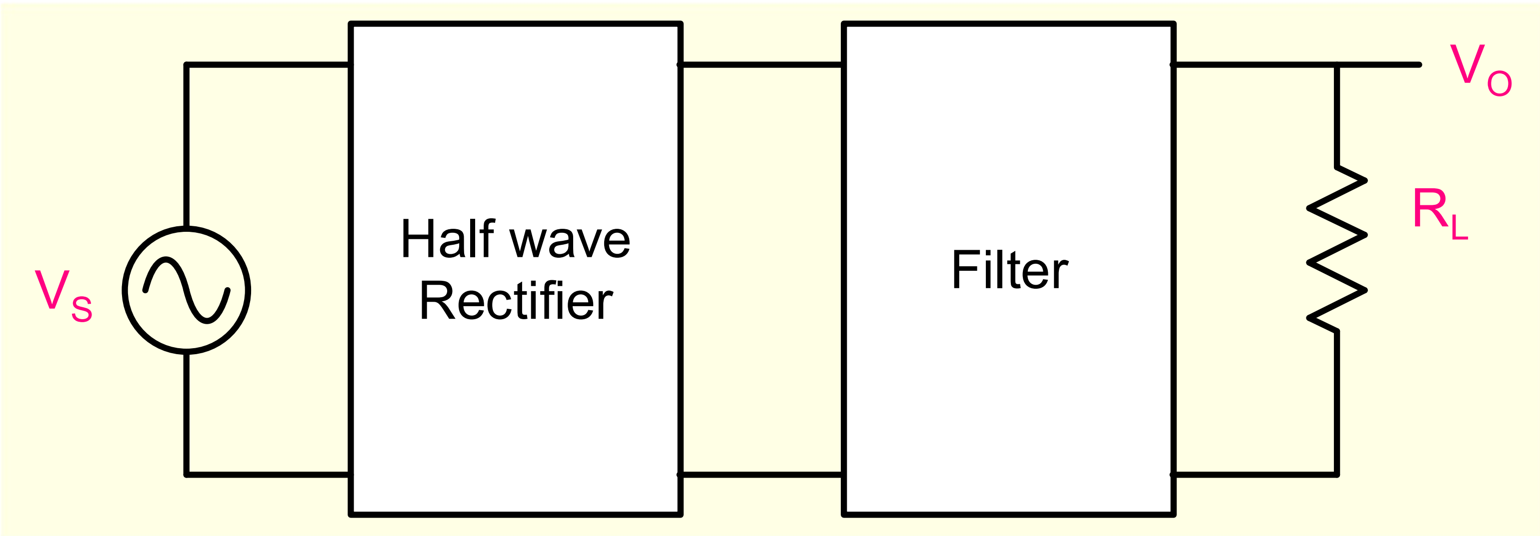
$$220V\ rms \Rightarrow 311.127V\ \ peak\ value$$



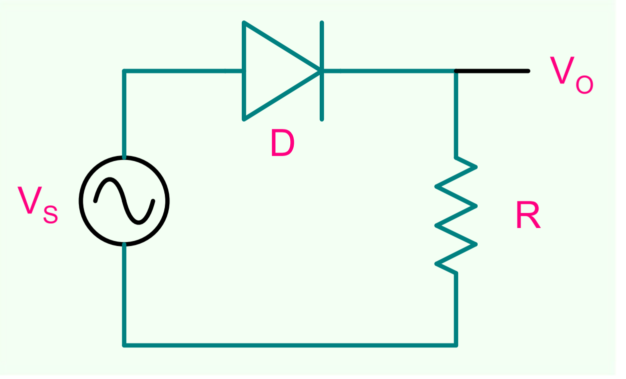
Strategy



Power Supply: Block diagram

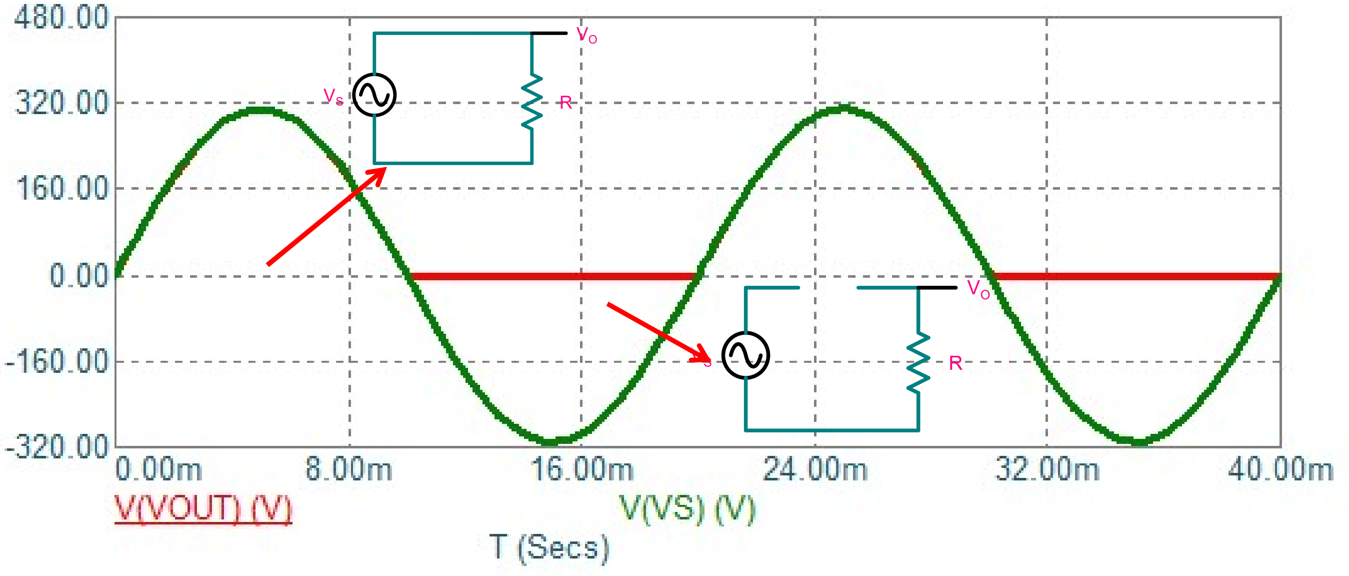


Half wave Rectifier circuit

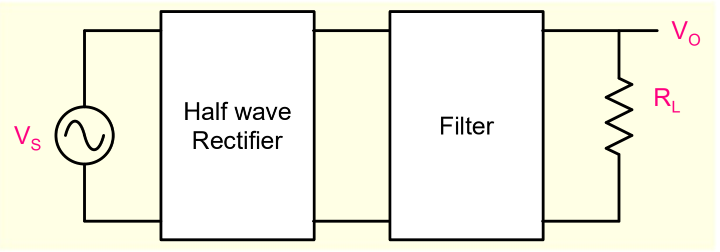


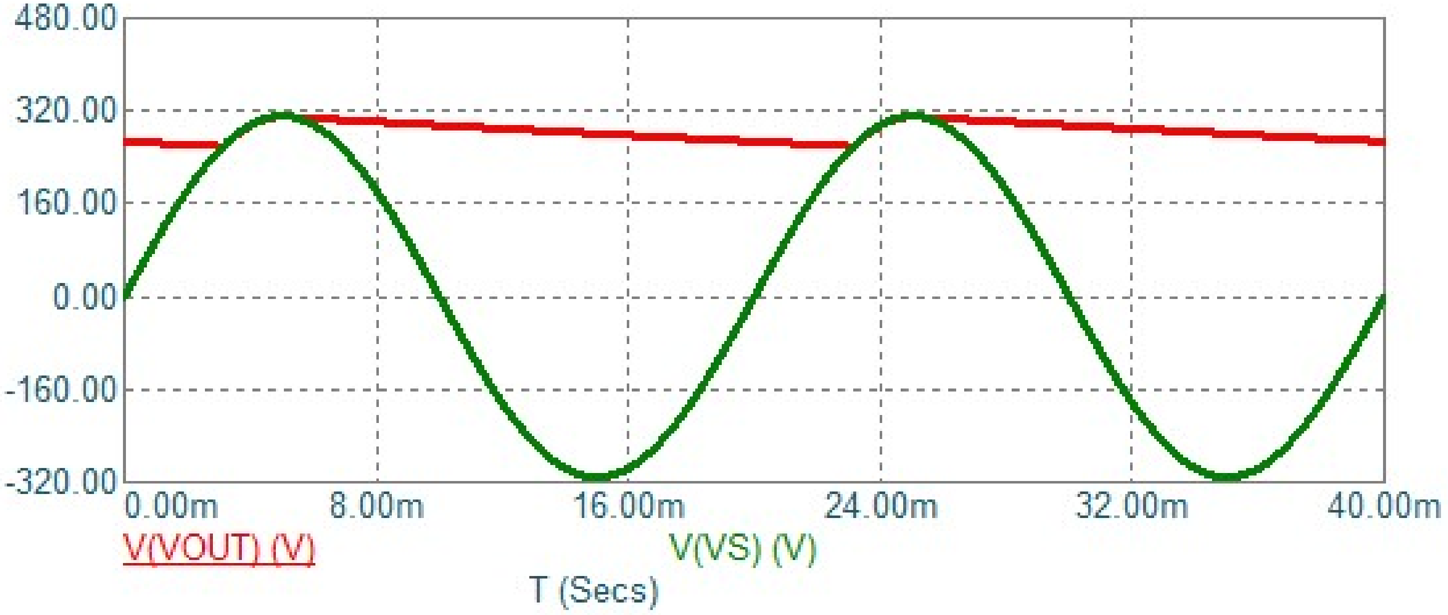
$$220V\ rms$$

$$220V \times \sqrt{2}$$
$$= 311.127V\ \ peak\ value$$



Filtered output voltage is too large !

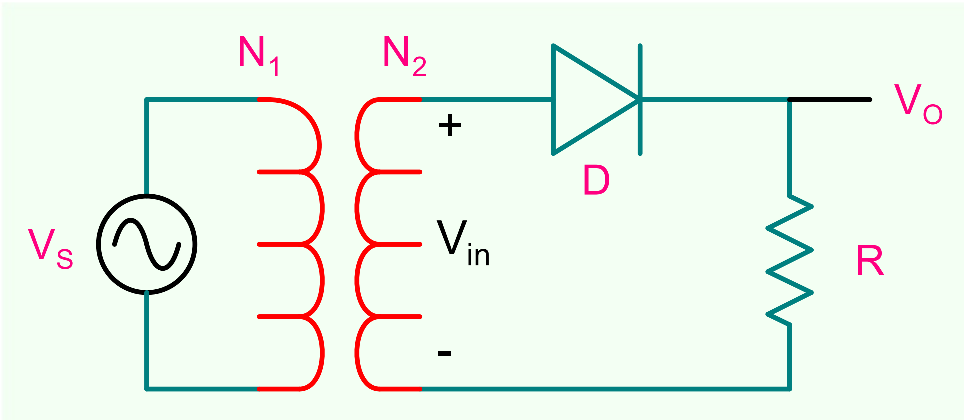


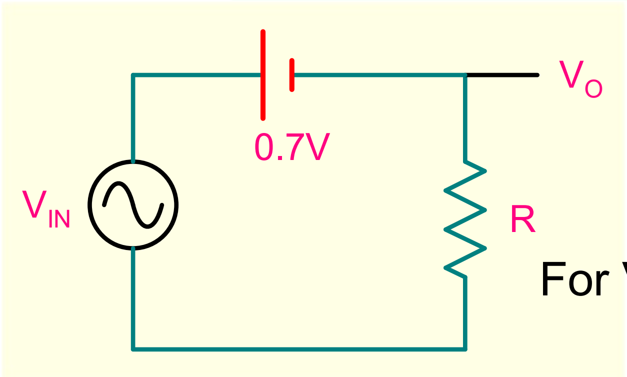


Must reduce the input voltage

Half Wave Rectifier

$$\frac{V_S}{V_{IN}} = \frac{N_1}{N_2}$$

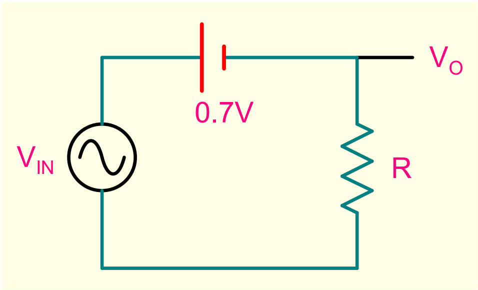




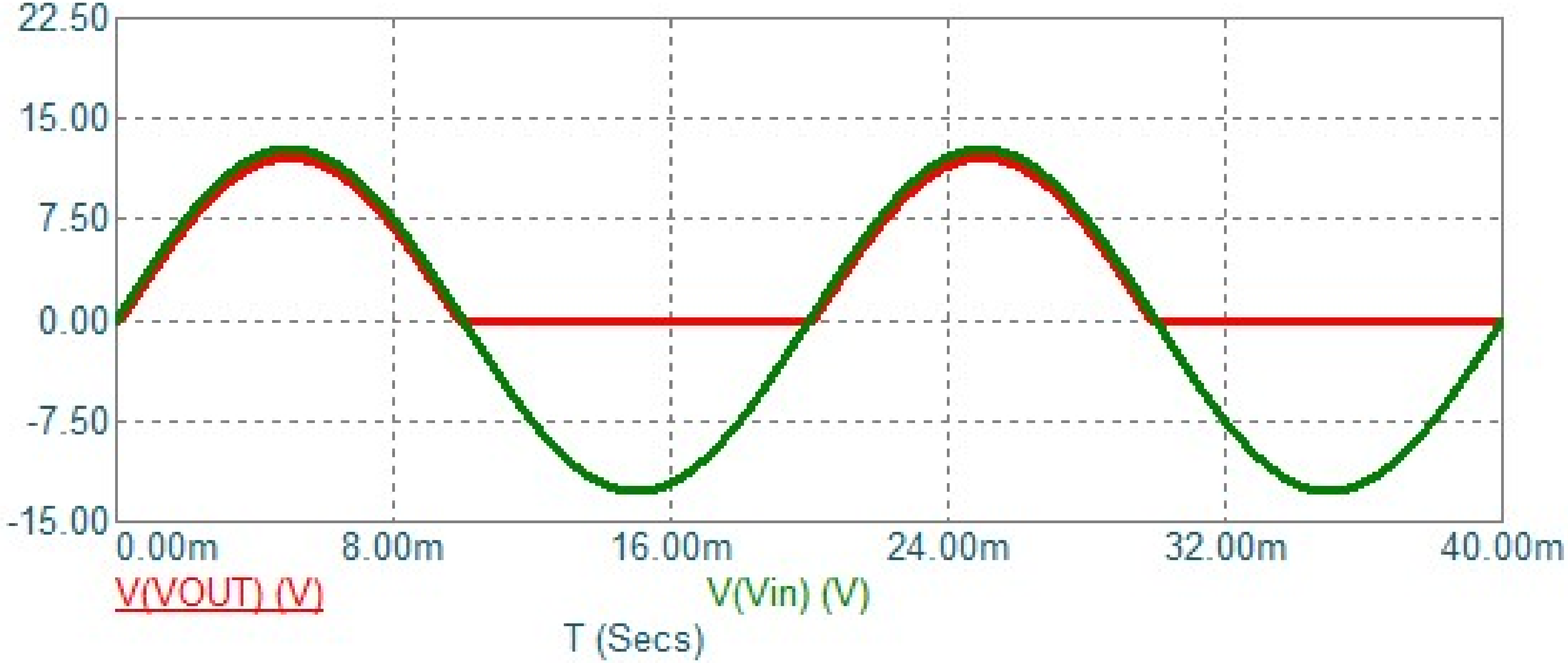
For V_O to be 12V, the input V_{IN} should be ~12.7V

$$V_S = 220V \times \sqrt{2}$$
$$= 311.127V \ \textit{peak value}$$

$$\frac{N_1}{N_2} = 24.5$$

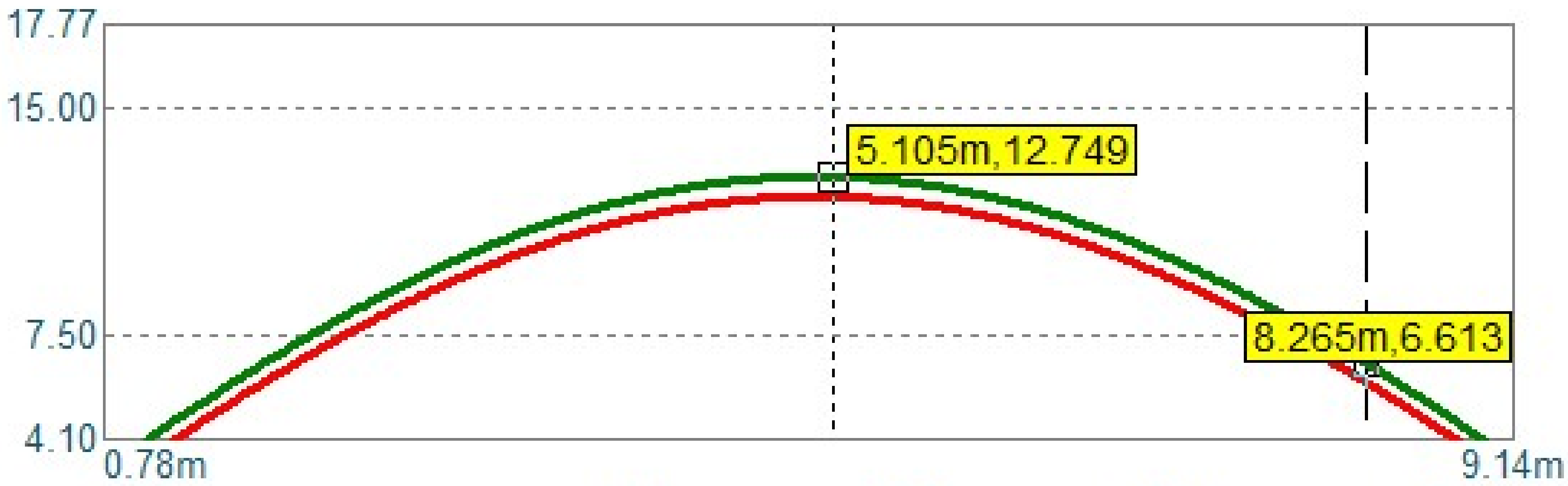


0.7V
V_O
V_IN
R

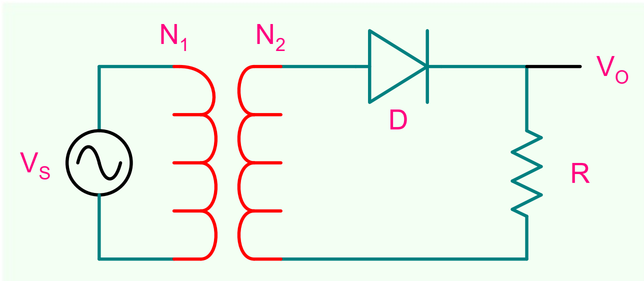


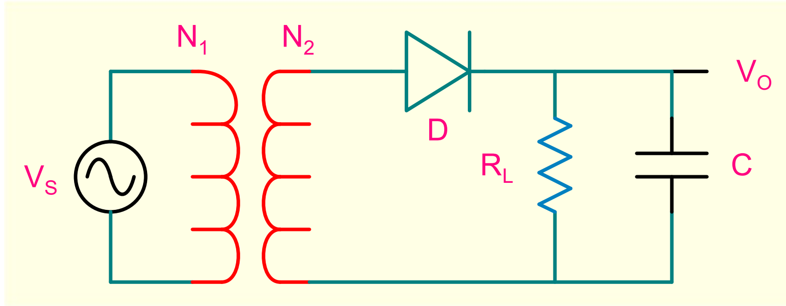
22.50
15.00
7.50
0.00
-7.50
-15.00
0.00m
8.00m
16.00m
24.00m
32.00m
40.00m
V(VOUT) (V)
V(Vin) (V)
T (Secs)

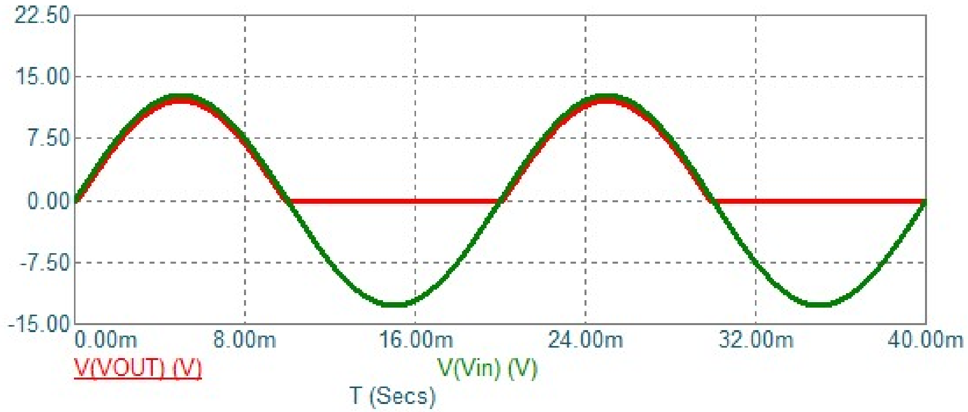
Zoomed view

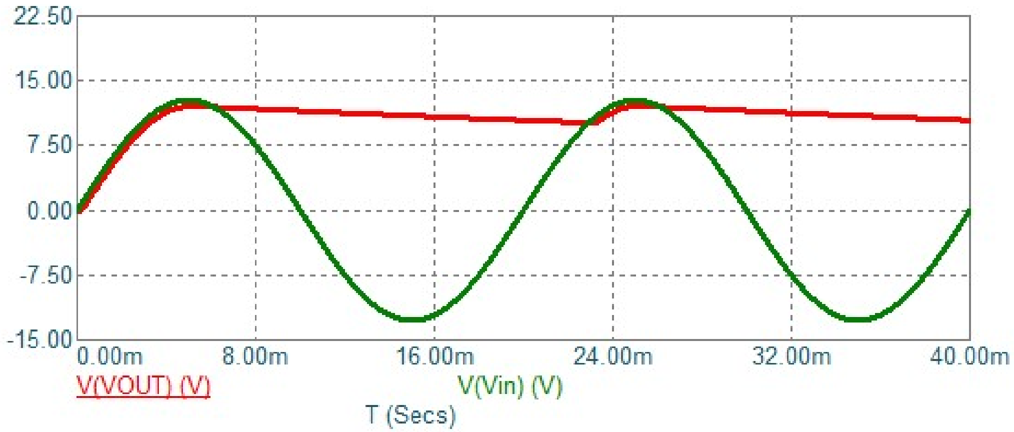


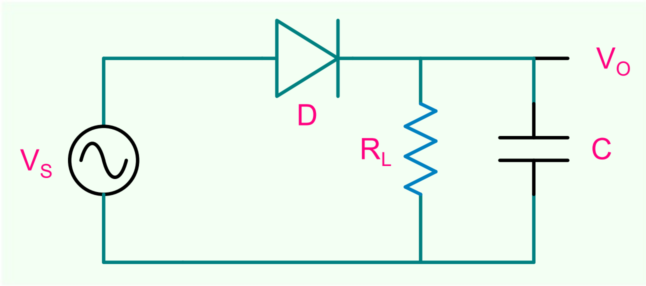
	Left	Right	Delta	Slope
V(VOUT) (V)	12.088	5.983	-6.105	-1.932K
V(Vin) (V)	12.749	6.613	-6.136	-1.942K
T (Secs)	5.105m	8.265m	3.160m	1.000


N1
N2
D
VO
VS
R

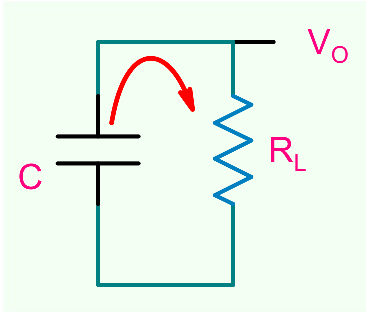

N1
N2
D
VO
VS
RL
C


22.50
15.00
7.50
0.00
-7.50
-15.00
0.00m
8.00m
16.00m
24.00m
32.00m
40.00m
V(VOUT) (V)
V(Vin) (V)
T (Secs)

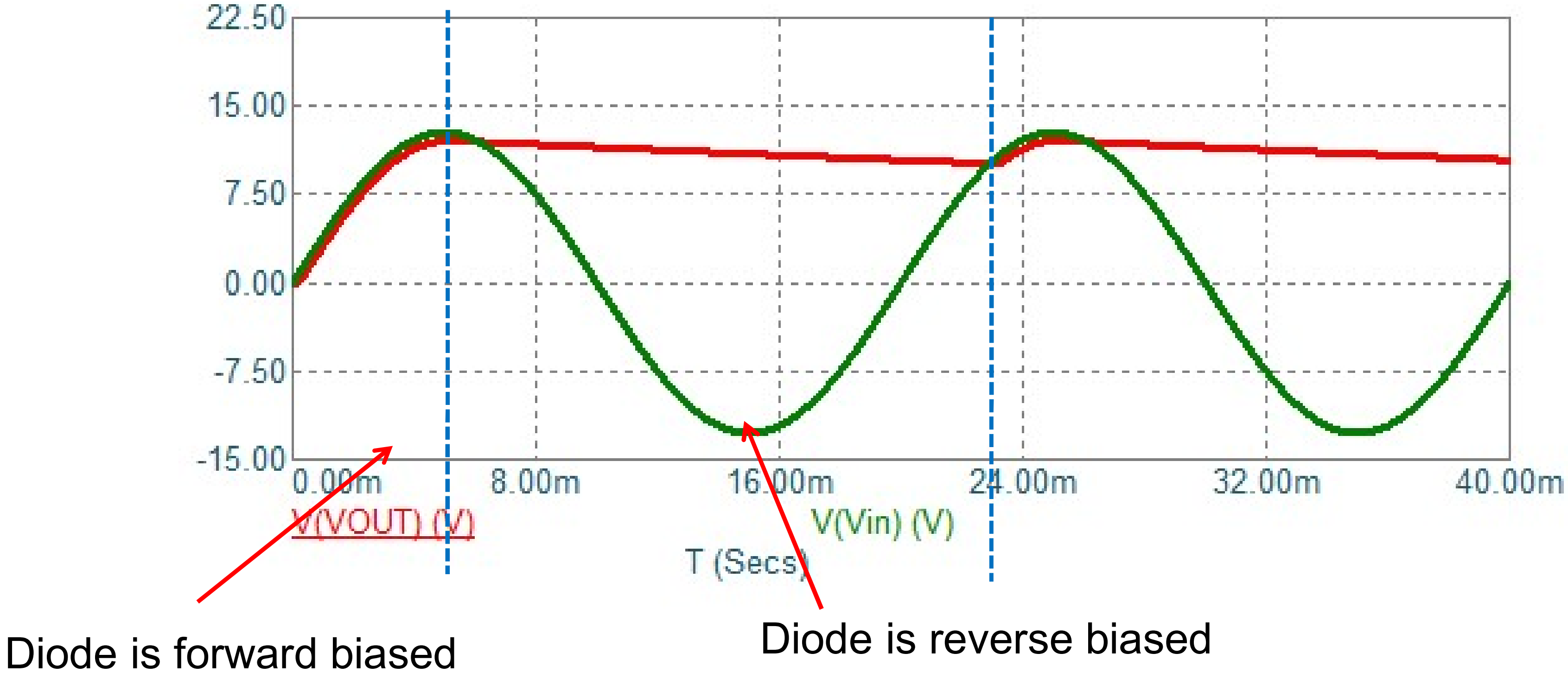

22.50
15.00
7.50
0.00
-7.50
-15.00
0.00m
8.00m
16.00m
24.00m
32.00m
40.00m
V(VOUT) (V)
V(Vin) (V)
T (Secs)



V_O
D
V_S
R_L
C



V_O
C
R_L



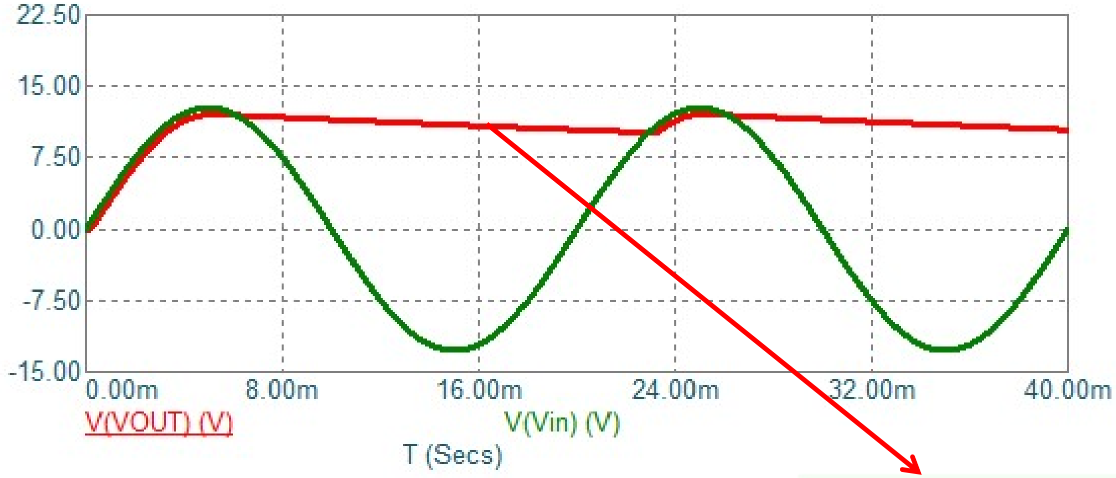
22.50
15.00
7.50
0.00
-7.50
-15.00
0.00m
8.00m
16.00m
24.00m
32.00m
40.00m
V(VOUT) (V)
V(Vin) (V)
T (Secs)
Diode is forward biased
Diode is reverse biased

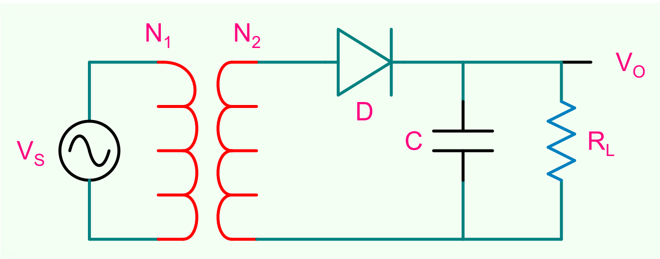
Output has a ripple

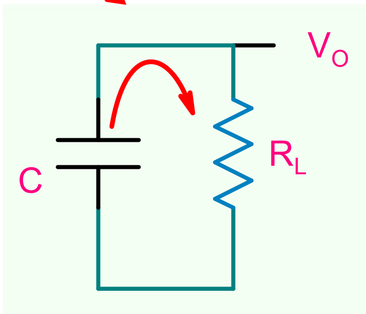
Ripple Voltage : $V_r = V_M - V_L$

Average Output Voltage : $V_O(avg) \cong V_M - \dfrac{V_R}{2}$

What does ripple voltage depend on?

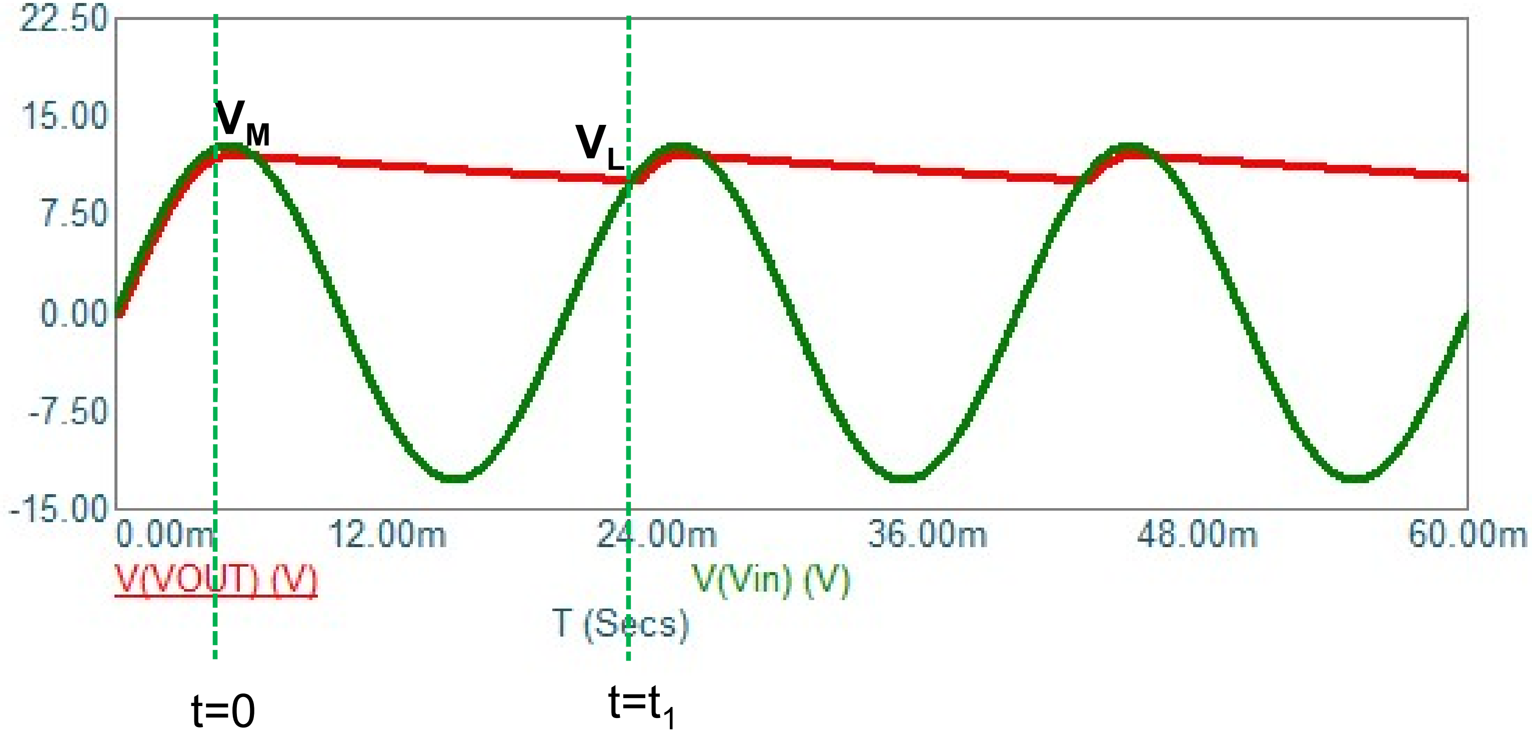






$$C\frac{dV_O}{dt} + \frac{V_O}{R_L} = 0 \Rightarrow \frac{dV_O}{dt} = -\frac{V_O}{R_L C}$$

$$V_O(t) = V_M \times e^{-\frac{t}{R_L C}}$$

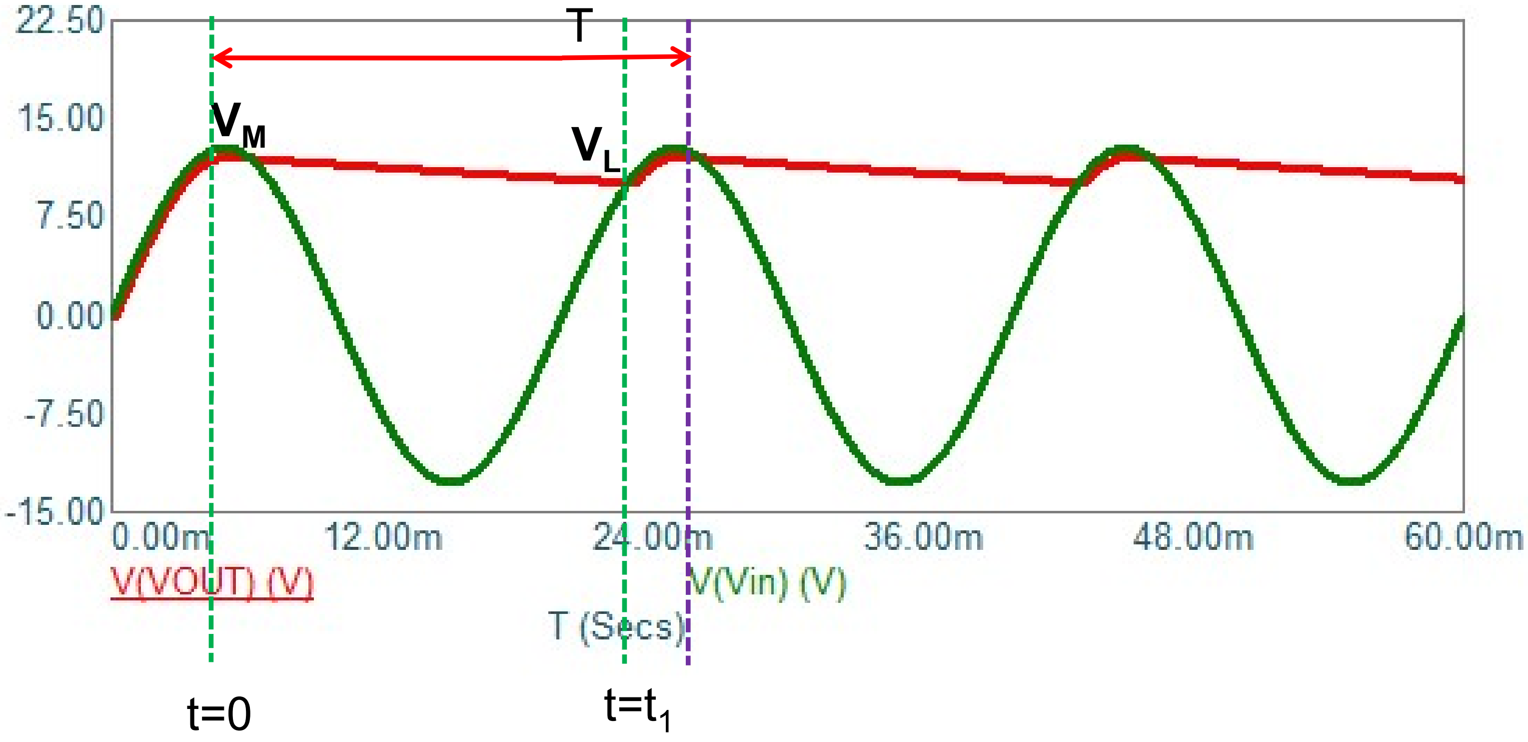


$$V_L = V_M \times e^{-\frac{t_1}{R_L C}}$$

$$V_r = V_M - V_L = V_M \times (1 - e^{-\frac{t_1}{R_L C}})$$

$$V_r \cong V_M \times \{1 - (1 - \frac{t_1}{R_L C})\} = \frac{V_M t_1}{R_L C}$$

Assuming that $t_1 << R_L C$

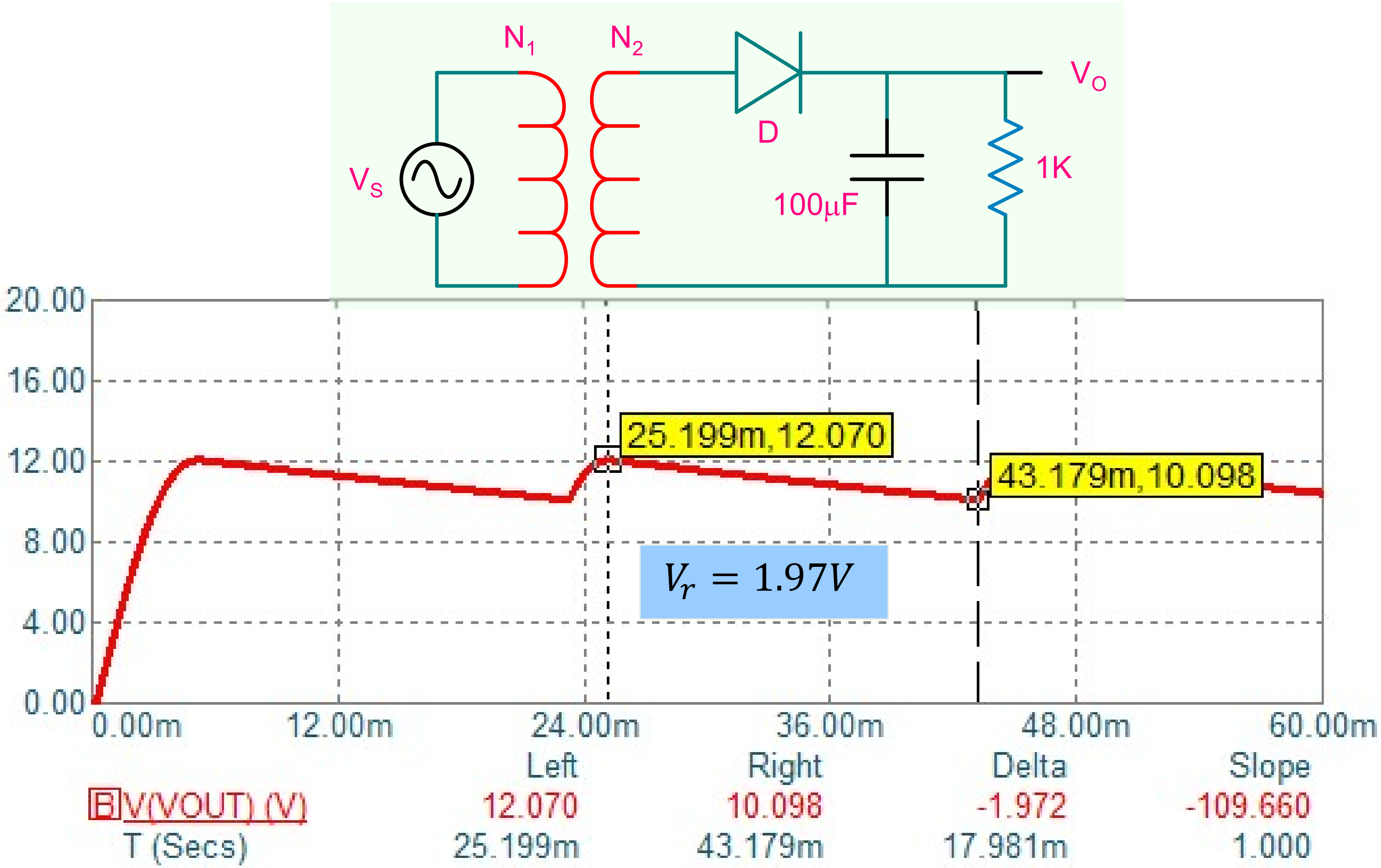


$$t_1 \cong T$$

$$V_r = \frac{V_M t_1}{R_L C} \cong \frac{V_M T}{R_L C}$$

$$V_r \cong \frac{V_M}{f \times R_L C}$$

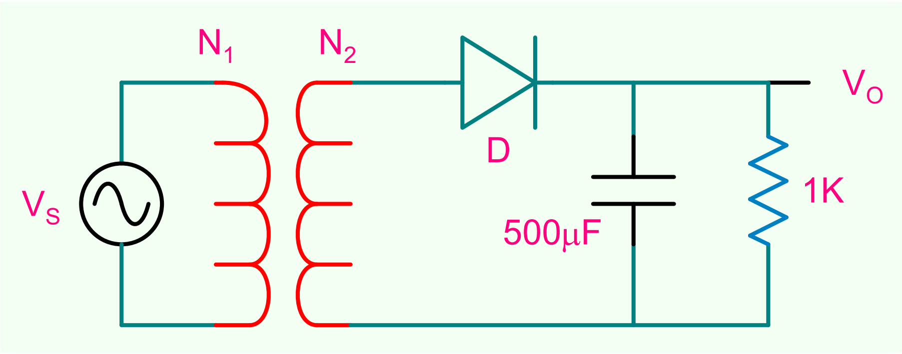
Example

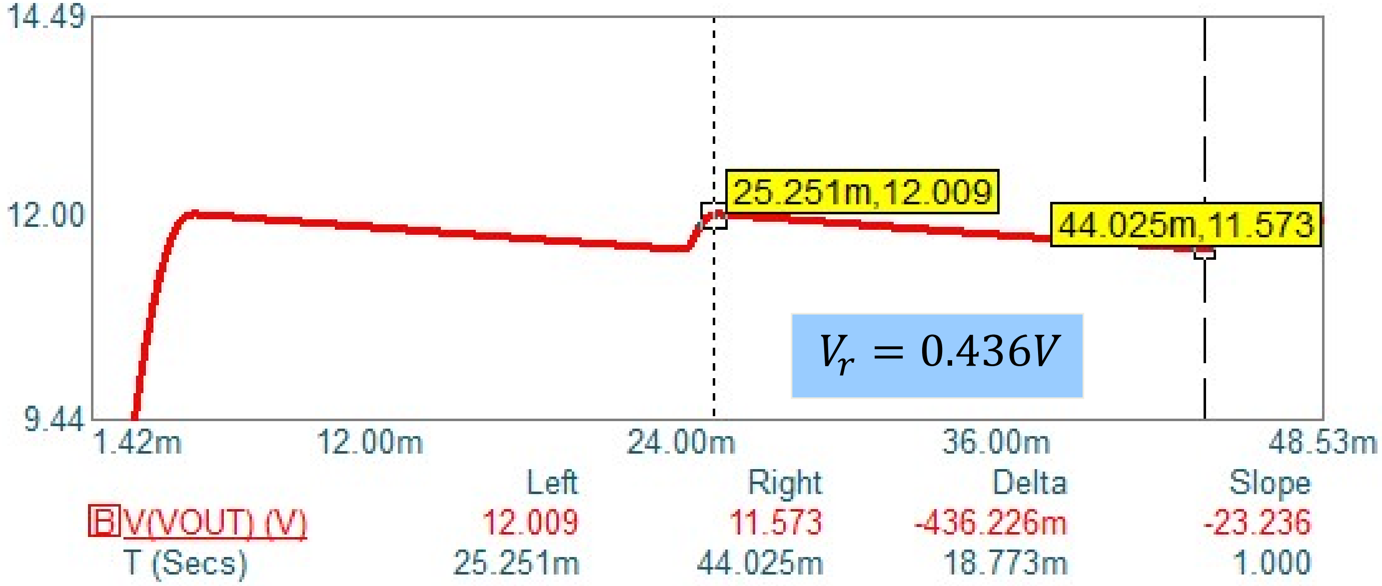


$$V_r \cong \frac{V_M}{f \times R_L\, C} = \frac{12.070}{50 \times 10^3 \times 100 \times 10^{-6}} = 2.4V$$

$$\frac{R_L C}{T} = 5$$

Example



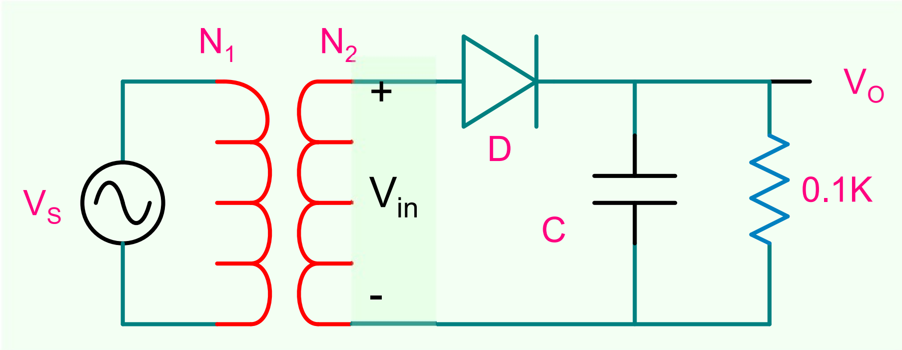


$$V_r \cong \frac{V_M}{f \times R_L\, C} = \frac{12}{50 \times 10^3 \times 500 \times 10^{-6}} = 0.48V$$

$$\frac{R_L C}{T} = 25$$

Design Example

Design a power supply that will supply 6V to a load of 100Ω with ripple voltage less than 0.1V.



For V_O to be 6V, the input V_{IN} should be ~6.7V

$$\frac{N_1}{N_2} = \frac{311.127}{6.7} = 46.4$$

$$V_r \cong \frac{V_M}{fR_L C} = 0.1 \Rightarrow C = 12mF$$

How do we choose a diode for this application?

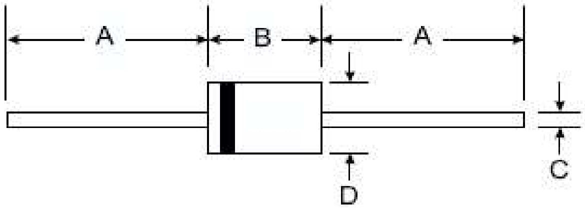
Diode Specifications

1N4001/L - 1N4007/L

1.0A RECTIFIER

Features

- Diffused Junction
- High Current Capability and Low Forward Voltage Drop
- Surge Overload Rating to 30A Peak
- Low Reverse Leakage Current
- Plastic Material: UL Flammability Classification Rating 94V-0



	DO-41 Plastic		A-405	
Dim	Min	Max	Min	Max
A	25.40	—	25.40	—
B	4.06	5.21	4.10	5.20
C	0.71	0.864	0.53	0.64
D	2.00	2.72	2.00	2.70
All Dimensions in mm				

"L" Suffix Designates A-405 Package
No Suffix Designates DO-41 Package

Mechanical Data

- Case: Molded Plastic
- Terminals: Plated Leads Solderable per MIL-STD-202, Method 208
- Polarity: Cathode Band
- Weight: DO-41 0.30 grams (approx)
  A-405 0.20 grams (approx)
- Mounting Position: Any
- Marking: Type Number

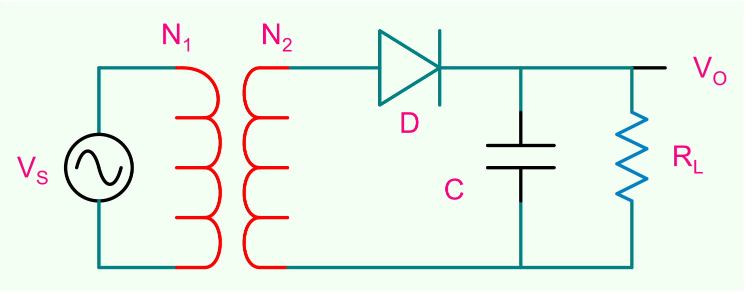
Maximum Ratings and Electrical Characteristics
@ $T_A = 25°C$ unless otherwise specified

Single phase, half wave, 60Hz, resistive or inductive load.
For capacitive load, derate current by 20%.

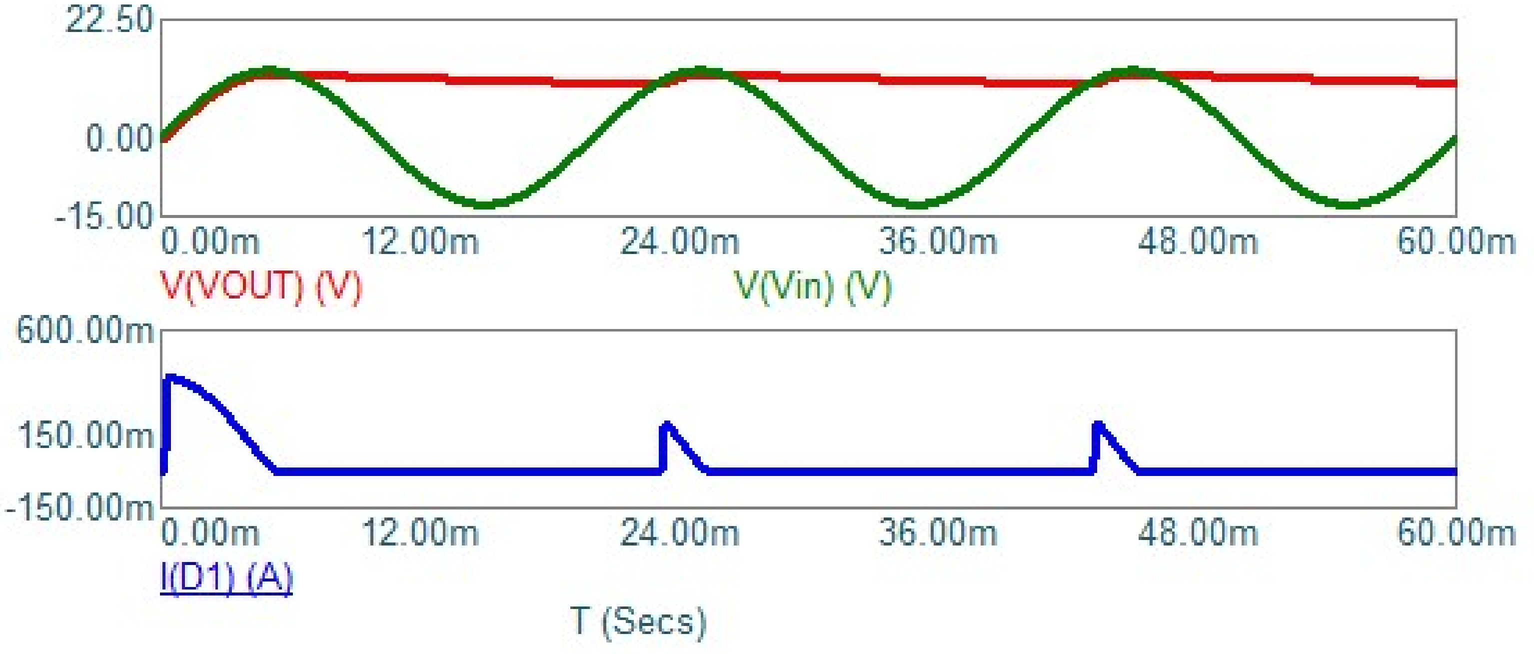
Characteristic	Symbol	1N 4001/L	1N 4002/L	1N 4003/L	1N 4004/L	1N 4005/L	1N 4006/L	1N 4007/L	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	V
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	V
Average Rectified Output Current (Note 1) @ $T_A = 75°C$	I_O	1.0							A
Non-Repetitive Peak Forward Surge Current 8.3ms single half sine-wave superimposed on rated load (JEDEC Method)	I_{FSM}	30							A
Forward Voltage @ $I_F = 1.0A$	V_{FM}	1.0							V
Peak Reverse Current @ $T_A = 25°C$ at Rated DC Blocking Voltage @ $T_A = 100°C$	I_{RM}	5.0 50							μA
Typical Junction Capacitance (Note 2)	C_j	15				8			pF
Typical Thermal Resistance Junction to Ambient	$R_{\theta JA}$	100							K/W
Maximum DC Blocking Voltage Temperature	T_A	+150							°C
Operating and Storage Temperature Range (Note 3)	T_j, T_{STG}	-65 to +175							°C

Notes:
1. Leads maintained at ambient temperature at a distance of 9.5mm from the case.
2. Measured at 1. MHz and applied reverse voltage of 4.0V DC.
3. JEDEC Value.

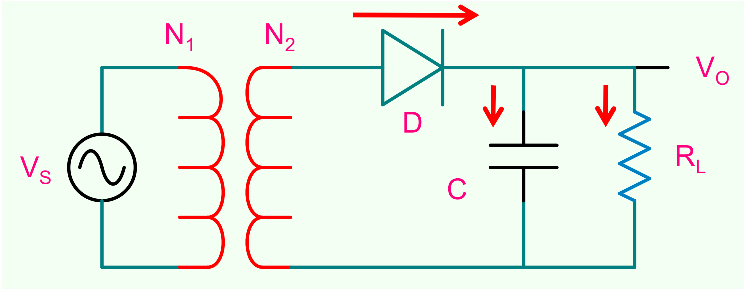
How do we choose a diode for this application?



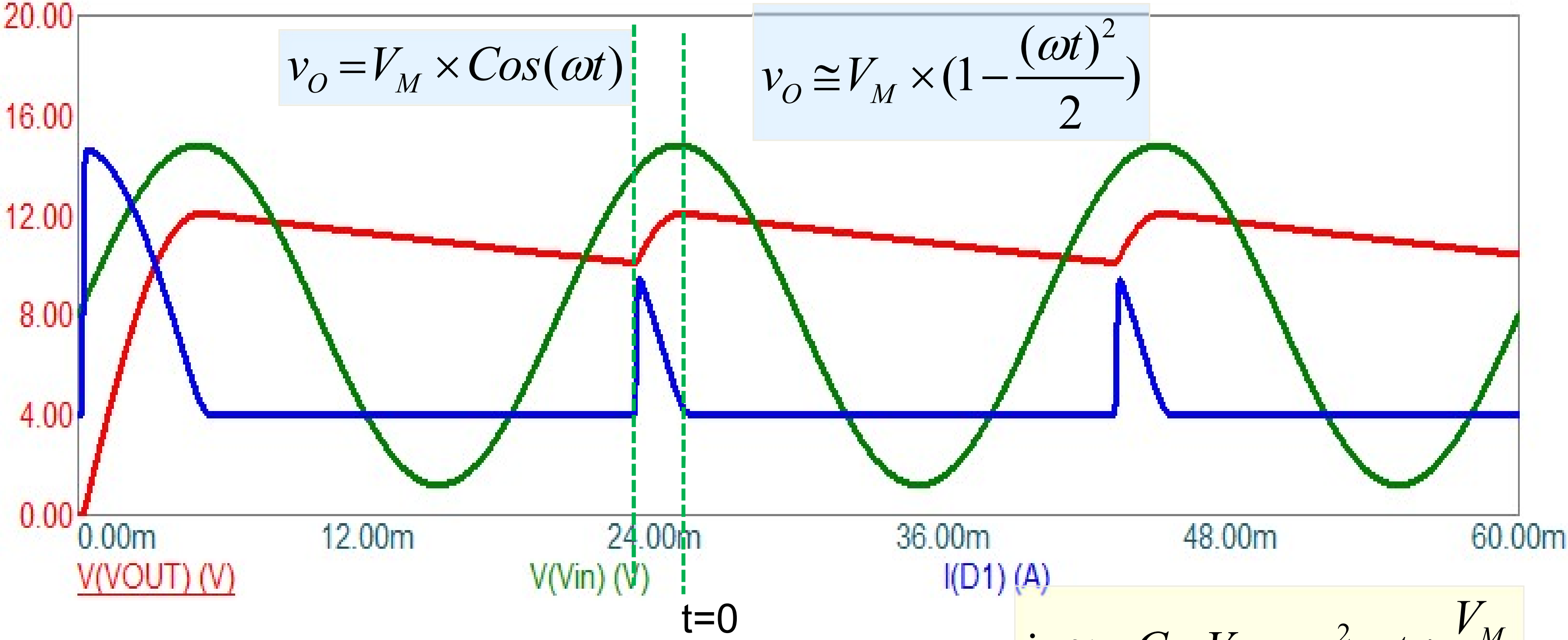
Determine peak and average diode currents; peak inverse voltage



Diode forward bias current



$$i_D = C \times \frac{dv_O}{dt} + \frac{v_O}{R_L}$$



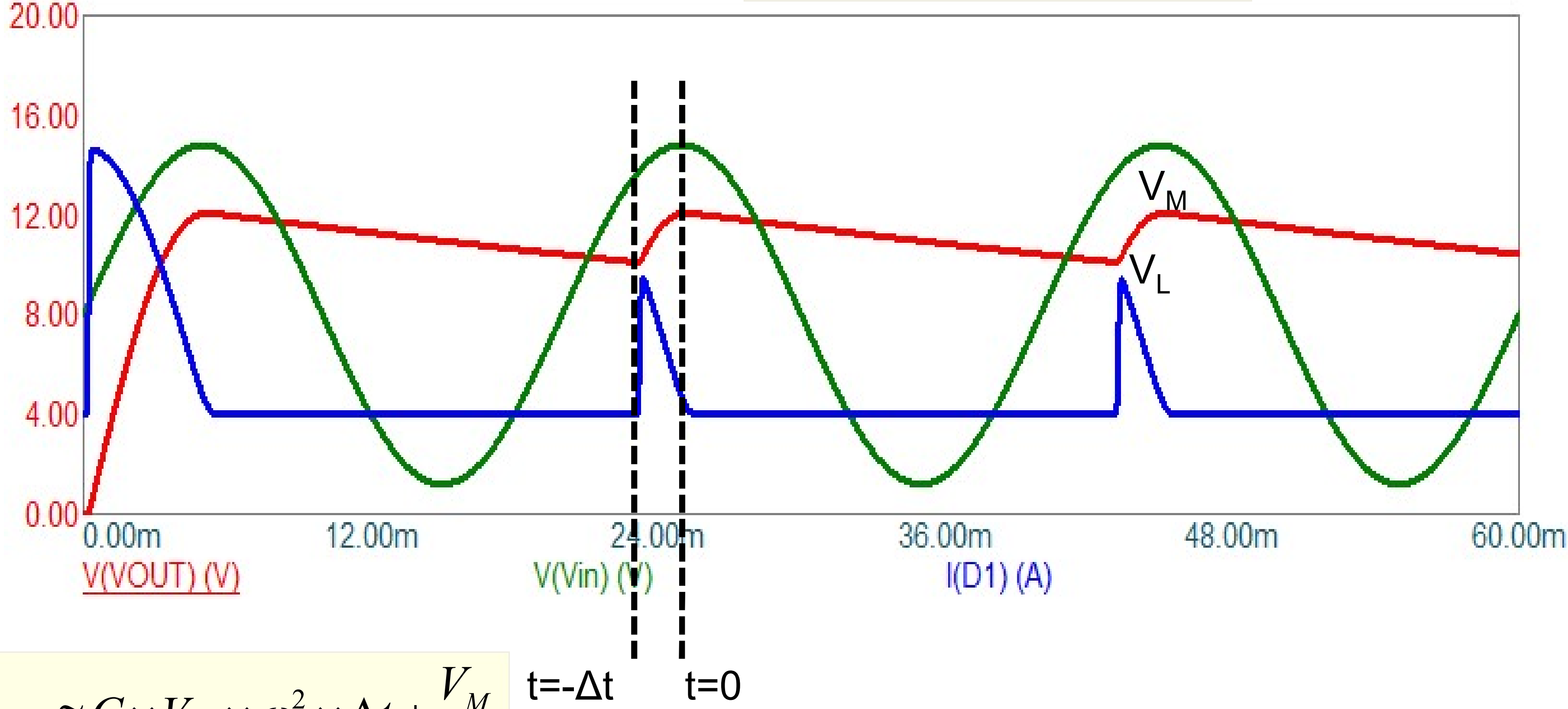
$$v_O = V_M \times Cos(\omega t)$$

$$v_O \cong V_M \times (1 - \frac{(\omega t)^2}{2})$$

$$i_D \cong -C \times V_M \times \omega^2 \times t + \frac{V_M}{R_L}$$

$$v_O \cong V_M \times (1 - \frac{(\omega t)^2}{2})$$

$$i_D \cong -C \times V_M \times \omega^2 \times t + \frac{V_M}{R_L}$$



$$i_{D\max} \cong C \times V_M \times \omega^2 \times \Delta t + \frac{V_M}{R_L}$$

$$V_L \cong V_M \times (1 - \frac{(\omega \Delta t)^2}{2}) \Rightarrow \Delta t = \frac{1}{\omega}\sqrt{\frac{2V_r}{V_M}}$$

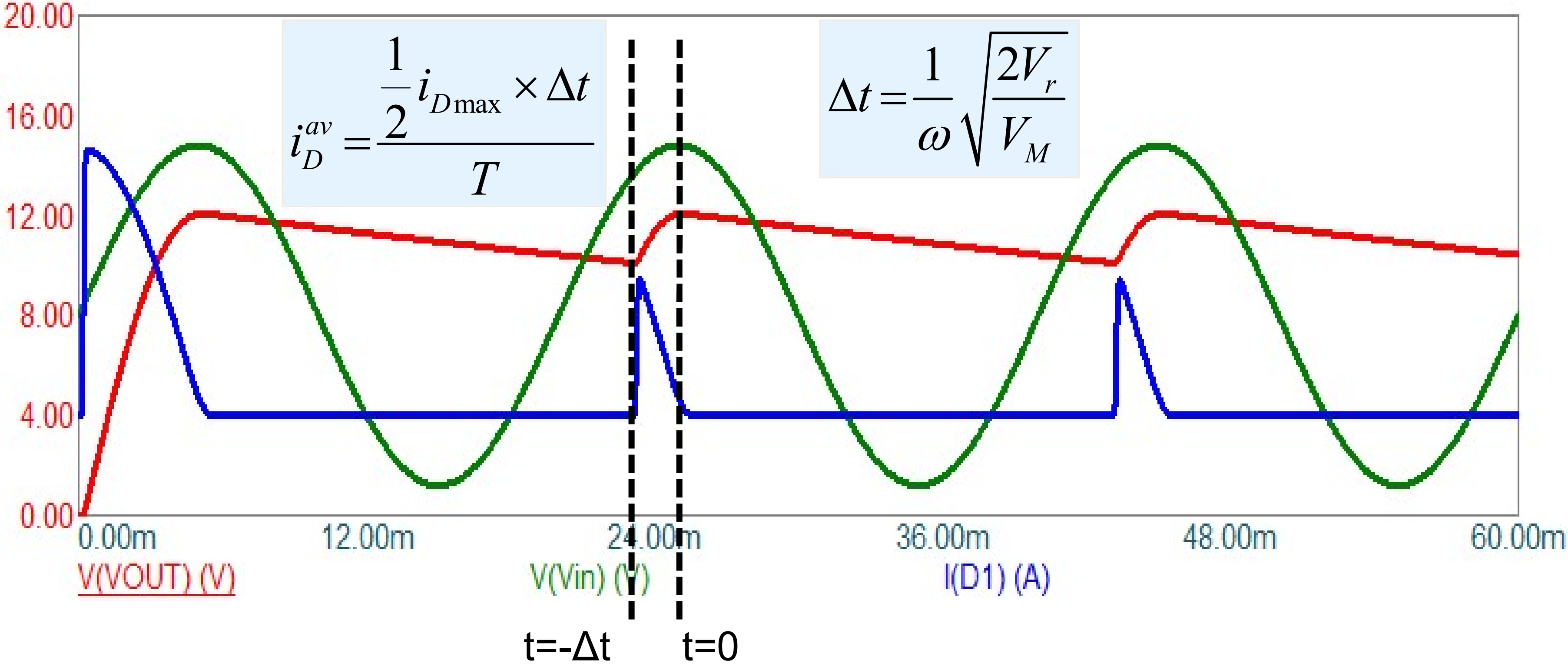
$$i_{D\max} \cong \omega C \times \sqrt{2V_r V_M} + \frac{V_M}{R_L}$$

Peak and Average Diode Currents

$$i_{D\max} \cong \omega C \times \sqrt{2V_r V_M} + \frac{V_M}{R_L}$$

$$i_D^{av} = \frac{\frac{1}{2} i_{D\max} \times \Delta t}{T}$$

$$\Delta t = \frac{1}{\omega}\sqrt{\frac{2V_r}{V_M}}$$



$$i_D^{av} = \frac{i_{D\max}}{4\pi} \times \sqrt{\frac{2V_r}{V_M}}$$

$$i_D^{av} = \frac{V_M}{R_L} + \frac{\sqrt{2V_r V_M}}{4\pi R_L} \cong \frac{V_M}{R_L}$$

$$i_{D\max} \cong \omega C \times \sqrt{2V_r V_M} + \frac{V_M}{R_L}$$

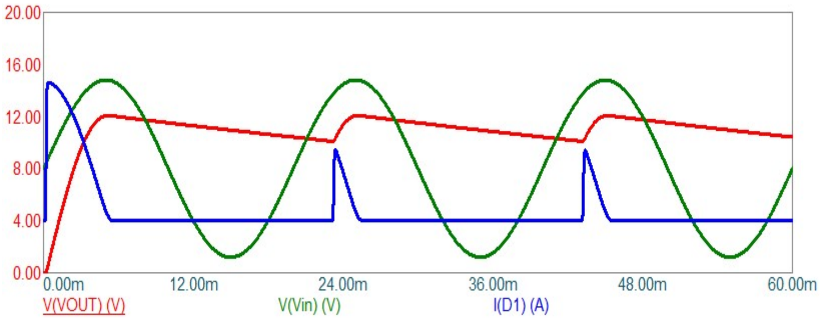
$$V_r \cong \frac{V_M}{f R_L C}$$

$$i_{Davg.} \cong \frac{V_M}{R_L}$$

$$i_{D\max} \cong 2\pi \times \sqrt{2f \times C \times V_M \times i_{Davg.}} + i_{Davg.}$$

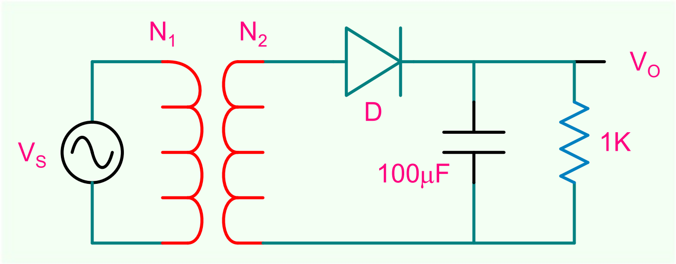
$$i_{D\max} \cong 2\pi \times \sqrt{2f \times C \times V_M \times i_{Davg.}}$$

$$\left(\frac{i_{Dmax}}{i_{Davg}}\right) \times \sqrt{\frac{V_r}{V_M}} = 2\sqrt{2}\pi$$



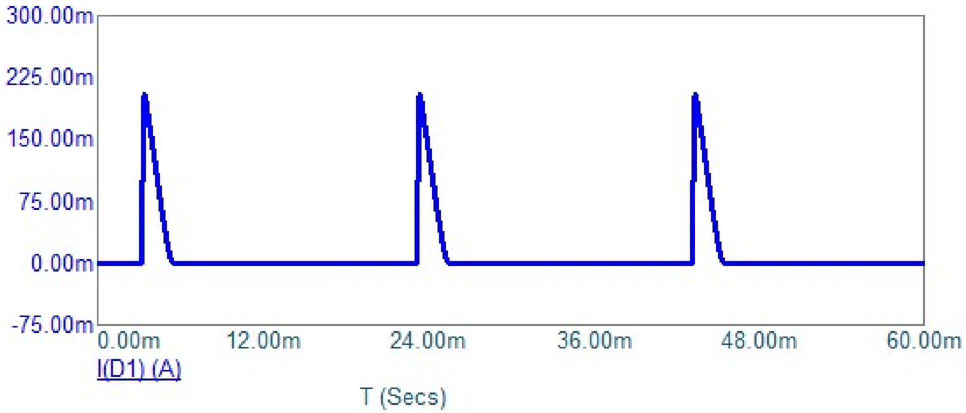
One can see a tradeoff between ripple voltage and peak diode current

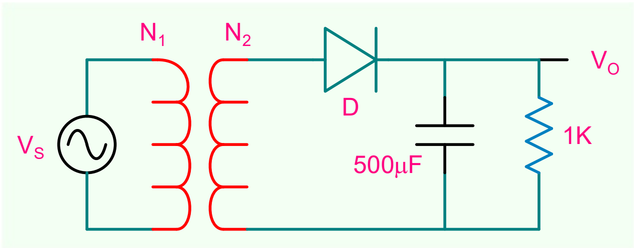
Peak and Average Diode Currents



$$V_r = 1.95V$$

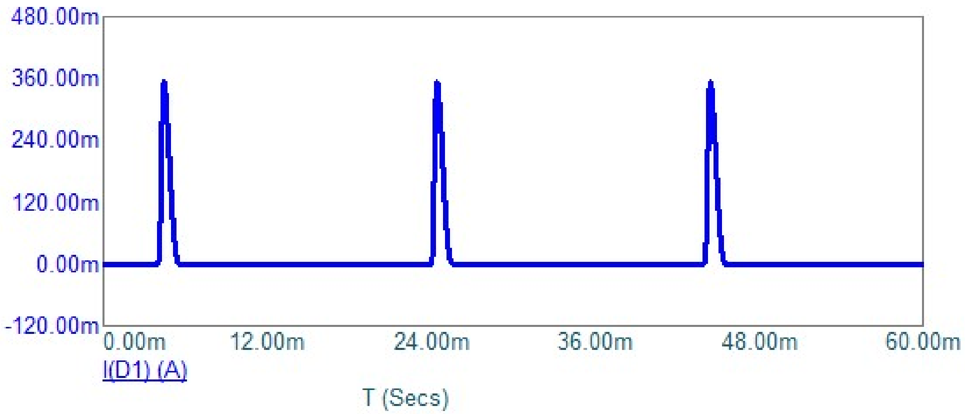
$$i_D^{av} \cong \frac{V_M}{R_L} = 12mA$$





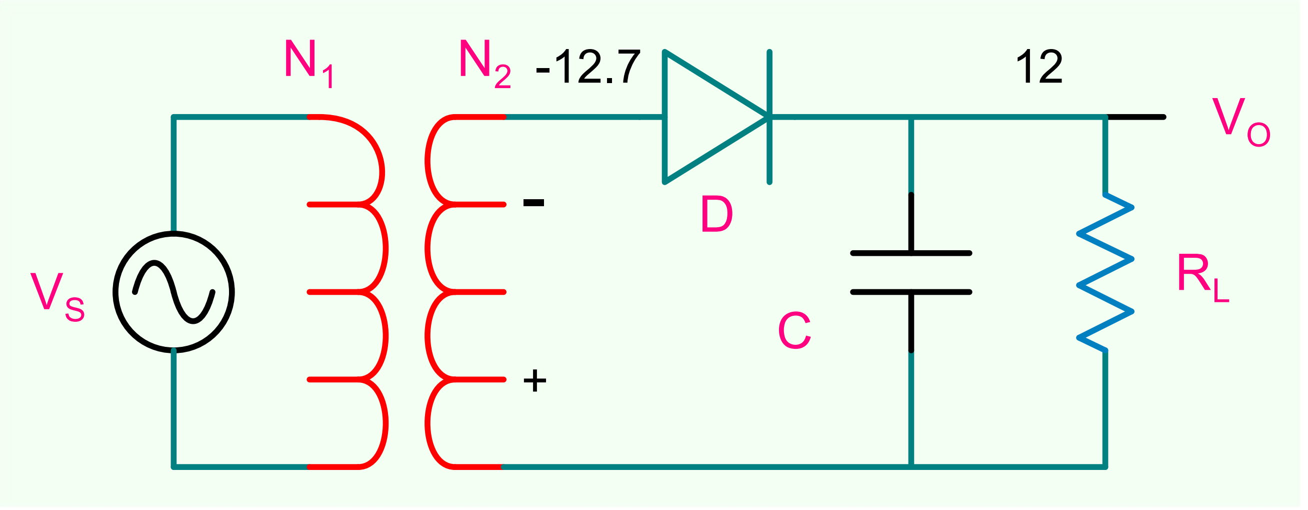
$$V_r = 0.438V$$

$$i_D^{av} \cong \frac{V_M}{R_L} = 12mA$$



Peak diode current increases as ripple reduces

Peak Inverse Voltage

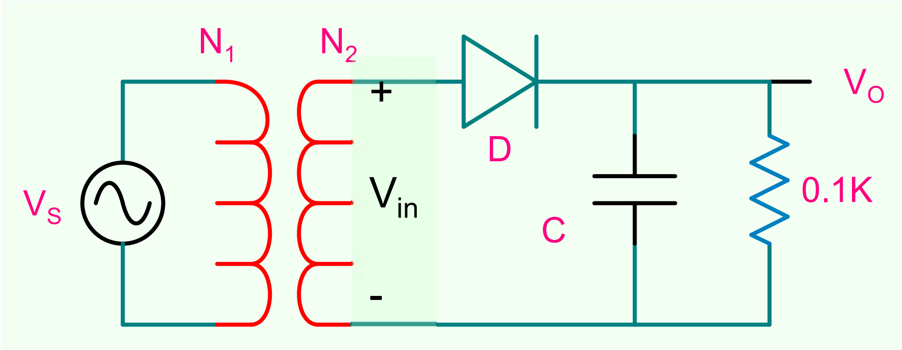


12+12.7=24.7V

$$PIV \cong 2v_O + 0.7$$

Design Example

Design a power supply that will supply 6V to a load of 100Ω with ripple voltage less than 0.1V.



$$i_{D\max} \cong \omega C \times \sqrt{2V_r V_M} + \frac{V_M}{R_L}$$

For V_O to be 6V, the input V_{IN} should be ~6.7V

$$\frac{N_1}{N_2} = \frac{311.127}{6.7} = 46.4$$

$$V_r \cong \frac{V_M}{fR_L C} = 0.1 \Rightarrow C = 12mF$$

How do we choose a diode for this application?

$$i_{Dmax} \approx \omega C \times \sqrt{2V_r \times V_M} + \frac{V_M}{R_L} = 344A$$

$$i_D^{av} \cong \frac{V_M}{R_L} = 60mA$$

$$PIV \cong 2v_O + 0.7 = 12.7V$$